UNITED STATES DEPARTMENT OF LABOR
Frances Perkins, Secretary
CHILDREN'S BUREAU . . . Katharine F. Lenroot, Chief

Occupational Hazards to Young Workers

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Report No. 6

RADIOACTIVE SUBSTANCES

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OCCUPATIONAL HAZARDS TO YOUNG WORKERS

Report No. 1. The Explosives-Manufacturing Industries, Publication No. 273.
Report No. 2. Motor-Vehicle Drivers and Helpers, Publication No. 274.
Report No. 3. The Coal-Mining Industry, Publication No. 275.
Report No. 4. The Logging and Sawmilling Industries, Publication No. 276.
Report No. 5. Woodworking Machines, Publication No. 277.
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LETTER OF TRANSMITTAL

United States Department of Labor,
Children's Bureau,
Washington, October 12, 1942.

Madam: There is transmitted herewith a report on the occupational hazards to young workers of employment in occupations involving exposure to radioactive substances. This investigation is the sixth of a series conducted by the Children's Bureau to guide the Chief of the Bureau in determining occupations particularly hazardous for young workers and therefore subject to an 18-year minimum-age standard under the Fair Labor Standards Act of 1938. The report was originally published in mimeographed form on March 4, 1942, and a hearing was held on the proposed order on March 25, 1942. This order, Hazardous Occupations Order No. 6, became effective on May 1, 1942, and declares work in certain occupations involving exposure to radioactive substances particularly hazardous for minors 16 and 17 years of age. A copy of the order is included in this report as Appendix B.

The Children's Bureau is indebted to employers engaged in the manufacture and use of self-luminous compound and the manufacture of incandescent mantles, for their cooperation in making available information which is included in this report. The Bureau is especially indebted to the following persons who generously gave their time to review the preliminary draft of the report, and to contribute their comment upon it:

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S. C. Lind, dean, School of Chemistry, Institute of Technology, University of Minnesota, Minneapolis.
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The investigation was made and the report prepared by William M. Schmidt, M. D., medical consultant, under the general direction of Beatrice McConnell, Director, and Elizabeth Johnson, Assistant Director in Charge of Research, of the Industrial Division of the Children's Bureau.

Respectfully submitted.

KATHARINE F. LENROOT, *Chief*.

HON. FRANCES PERKINS,
Secretary of Labor.

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OCCUPATIONAL HAZARDS TO YOUNG WORKERS

Radioactive Substances

The child-labor provisions of the Fair Labor Standards Act of 1938, which established a minimum age of 16 years for general employment, provide for a minimum age of 18 years for employment in those occupations determined by the Chief of the Children's Bureau to be particularly hazardous for minors 16 and 17 years of age or detrimental to their health or well-being. This report presents the findings of an investigation of the hazard of industrial exposure to radioactive substances in the manufacture and use of self-luminous compound and in the manufacture of incandescent gas, gasoline, and kerosene mantles. It provides the basis (1) for determining whether occupations in these industries are particularly hazardous for minors or detrimental to their health, and (2) for an order giving legal effect to the finding.[1]

Industries in which there is exposure to radioactive substances were selected for investigation because a number of cases of radium poisoning, most of which terminated in death, were reported after the first World War.[2] Many of these poisonings were of young women, and in a number of instances exposure had begun before the age of 18 years. In the present war period, an expansion is occurring in the luminous-compound industry similar to that which occurred during the period of the first World War. Employment in this field has increased markedly since early in 1940, and further increases are expected to occur. Finally, radium poisoning is generally progressive and very often terminates fatally.

The principal industrial processes in which radioactive substances are found are: (1) The self-luminous dial-painting industry, which includes the manufacture of self-luminous compound (containing radium or other radioactive material) and its application to watch, clock, and instrument dials and hands, and to other objects such as buttons of electric light fixtures; (2) the incandescent-mantle industry, which involves the impregnation of rayon with solutions of thorium nitrate and subsequent processing in the course of which radioactive emanation escapes into the air; (3) industrial radiography, in which radium is used for the production of radiographs by means of which imperfections in heavy castings may be detected; and (4) the refining of radium and mesothorium from radioactive ores and sands. The use of radium for medical purposes is not within the scope of this investigation.

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[1] The legal basis for the investigation is presented in the appendix, p. 17.

[2] Survey of Industrial Poisoning From Radioactive Substances. Monthly Labor Review (published by the Bureau of Labor Statistics, U. S. Department of Labor), Vol. 28, No. 6 (June 1929), pp. 21–61.

The luminous-dial industry and the incandescent-mantle industry form the subject of the present report. Industrial radiography and the refining of radium and mesothorium are highly specialized procedures employing few people. As it is very unlikely that minors under 18 years would be employed in them, these industries will not be discussed in this report.

PROCEDURE AND SOURCES OF STUDY

Several plants engaged in dial painting with self-luminous compound were visited, and the occupations, plant lay-out, and practices designed to control the hazards were observed. One plant engaged in the manufacture of incandescent mantles was visited for the same purpose.

The experience and opinions of persons directly connected with industries using radioactive substances were secured. Several of the principal employers were interviewed, as well as leading experts who had studied the hazards of exposure to radioactive substances. Information was secured from these persons not only on hazards but also on employment practices, and they were asked to express their judgment as to the reasonableness of establishing a minimum-age standard of 18 years for employment in occupations accompanied by exposure to radioactive substances.

The published reports of investigations by physicists, industrial hygienists, and other experts relating to the hazards of industrial exposure to radioactive substances were studied, including publications of the Bureau of Labor Statistics, the United States Public Health Service, and the recently issued National Bureau of Standards Handbook H27 entitled "Safe Handling of Radioactive Luminous Compound." References will be made to these sources in the body of the report.

HARMFUL EFFECT OF RADIOACTIVE SUBSTANCES

The important radioactive substances that may be used in self-luminous compound are radium and mesothorium sulphate, chloride, bromide, or other salts. Thorium nitrate, which is used for the manufacture of incandescent gas, gasoline, or kerosene mantles, is accompanied by radiothorium, a decay product of mesothorium. Radium, mesothorium, and radiothorium disintegrate naturally into a series of radioactive elements, and in the course of this process of disintegration powerful radiation is constantly emitted. One member of each radioactive series is a gas, radon in the radium series and thoron in the mesothorium series, and these gases, in equilibrium with their decay products, also give rise to radiation. When radioactive substances are deposited in the body, alpha particles, which are nuclei of helium atoms, are the most important of the radiations emitted. They are ejected from the radioactive atoms with great force and continually bombard the surrounding body tissues with destructive effect.

Since nearly all radioactive substances deposited in the body ultimately accumulate in the skeleton, the characteristic destructive effects are to be found in the bones. Anemia, radiation osteitis, and sarcoma of the bone are the principal pathologic results.

Anemia develops as a result of the disruptive effect of the alpha particle upon the blood-forming centers of the bone marrow. According to Martland,[3] who has made extensive and detailed studies of the pathology of radium poisoning, the first effect is that of an irritative stimulation of the bone marrow, and during this period, lasting perhaps several years, the subject may be in apparently good health. Ultimately, however, the bone marrow becomes exhausted and, especially in those cases having an early fatal termination, a very severe anemia develops. The bone-marrow changes which lead to the development of anemia have been interpreted and designated as the first stage of radiation osteitis, an inflammatory reaction of the bone resulting from radiation. The second stage is characterized by a replacement of patches of abnormal marrow by a highly cellular fibrous tissue. The third stage represents a change in these patchy areas to a relatively noncellular fibrous tissue, with considerable decalcification and absorption of bone. It is in this stage that bone structure is impaired to the point at which spontaneous fractures appear and other deforming lesions develop. Osteitis of the jaw is often complicated with infection arising from the teeth, leading to extensive necrosis of the mandible.

Some individuals with radium deposited in the body, who survived the earlier harmful effects of radium poisoning, developed malignant tumors of the bone. Martland describes 4 deaths from malignant tumors of the bone among 17 deaths causd by radioactive substances, and 4 additional cases of bone sarcoma among some 30 former dial painters alive at the time of his report but still radioactive.[4] Such malignant tumors may be single or multiple and manifest the characteristic progression and spread of bone sarcomas that are spontaneous in origin.

An observation of interest with reference to the protection of younger workers is that radium, like lead, tends to be deposited at the growing ends of the bones. A case was reported in 1938 of a girl whose exposure to radioactive substances occurred chiefly between her sixteenth and twenty-third years. X-rays of her extremities revealed lesions and abnormal union of the upper humeral and femoral epiphyses, which usually unite at about 20 and 18 years of age respectively.[5]

Apart from the radiation arising from stored radioactive solid, there is a constant emission of gaseous emanation: Radon from radium and thoron from thorium. Both these gases are exhaled in the expired air and themselves give rise to alpha radiation. A case of carcinoma of the paranasal sinuses has been reported in a radium-dial painter who was found to be radioactive. It is possible that this carcinoma of the paranasal sinuses arose from the local effect of radon constantly eliminated in the expired air over a period of years.[6]

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[3] The Occurrence of Malignancy in Radioactive Persons, by Harrison S. Martland. American Journal of Cancer, Vol. 15, No. 4 (October 1931), pp. 2435–2516.

[4] *Ibid.*, p. 2477.

[5] Effects of Treatment on Radium and Calcium Metabolism in the Human Body, by Joseph C. Aub, Robley D. Evans, Darius M. Gallagher, and Dorothy M. Tibbetts. Annals of Internal Medicine, Vol. 11, No. 8 (February 1938), pp. 1443–1463.

[6] Occupational Tumors—(6) Bones, by Harrison S. Martland, p. 18. Occupation and Health. International Labour Office, Geneva, October 1939.

In addition to the effects of deposition of radioactive substances in the body, harmful effects result also from excessive exposure to external radiation. Radium and mesothorium emit gamma rays, which are similar to X-rays but are much more penetrating. Just as excessive exposure to X-rays may result in various skin lesions and anemia, so excessive exposure to gamma rays leads to these disturbances. Experience with this type of radiation injury, however, is largely confined to laboratory workers and others whose exposure is limited to external radiation. When exposure to external radiation is combined with internal deposition of radioactive substances, the tolerance for both types of exposure may possibly be reduced.

The gaseous radioactive emanations of radium and mesothorium escape into the air in the course of some industrial operations involving radioactive substances. Such emanations, when inhaled, subject the lung tissues to the effect of radiation. While radiation from this source is neither continuous nor permanent, as is the radiation resulting from the deposition of radioactive solids in the body, it exists as long as an individual is exposed to an atmosphere containing a significant quantity of radon or thoron, and pathologic processes resulting from it may continue to develop long after exposure has ceased.[7] Malignant lung tumors have been reported in individuals with this type of exposure.

Radium poisoning was reported by Blum in 1924 and described by Martland and his coworkers in 1925 in a report of deaths among dial painters formerly employed in a plant in New Jersey.[8] The following brief summary of the early history of the New Jersey poisonings is based on a review by Martland published in 1929.[9]

> Between 1922 and 1924 nine girls who had been employed as watch-dial painters in a New Jersey plant died. There was no investigation of their deaths and no autopsies were performed, except for one 5 years after death for litigation purposes. In this case undisputed evidence of radioactivity was found in the bones.
>
> In 1925 Hoffman, whose attention had been called to the plant by the New Jersey Consumers' League, found that there was a great similarity in the reading of the death certificates of the deceased former employees. He was of the opinion that they represented an unusual occupational poisoning and thought that mesothorium in the plant was mainly responsible and that there was an ingestion of this paint as a result of the habit of licking the brushes. An investigation made in March 1924 at the request of the company was not published until August 1925.
>
> In 1926 two of the fatal cases were settled out of court by payment of a lump sum to the families, without assumption of any legal responsibility by the company. In May 1927 suit was started by five girls, and this also was settled out of court after a great deal of delay and a defense based in part on the statute of limitations.

In the survey of industrial poisoning from radioactive substances reported by the Bureau of Labor Statistics in 1929[10] and in a report on radium poisoning in 1931 by H. S. Martland,[11] a total of 48 definite or strongly suspected cases of radium poisoning is presented. Twenty-eight of them had resulted in death at the time of the reports. It appears that 14 persons among the 48 reported cases had begun work involving exposure to radioactive substances before the age of 18. and 19 had begun such work before the age of 20.

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[7] Occupational Cancer of the Lung, by L. Teleky. Journal of Industrial Hygiene and Toxicology, Vol. 19, No. 2 (February 1937), pp. 73–85.

[8] Some Unrecognized Dangers in the Use and Handling of Radioactive Substances; with especial reference to the storage of insoluble products of radium and mesothorium in the reticulo-endothelial system, by Harrison S. Martland, Philip Conlon, and Joseph P. Knef. Journal of the American Medical Association, Vol. 85, No. 23 (December 1925), pp. 1769–1776.

[9] Occupational Poisoning in Manufacture of Luminous Watch Dials, by Harrison S. Martland. Journal of the American Medical Association, Vol. 92, Nos. 6 and 7 (February 1929), pp. 466–473 and 552–559; reprinted in the Monthly Labor Review (published by the Bureau of Labor Statistics, U. S. Department of Labor), Vol. 28, No. 6 (June 1929), pp. 62–92.

[10] Survey of Industrial Poisoning from Radioactive Substances, p. 61.

New Jersey in 1926 added "mesothorium or radium necrosis" to its list of compensable occupational diseases. At the present time compensation for injury from radioactive substances has been expressly included in the schedules of 11 other States.[12]

In a report on occupational diseases in women for the period 1935–38, made by the Women's Bureau of the United States Department of Labor,[13] 6 cases of radium poisoning were stated to have been reported from Connecticut.[14] Compensation was awarded to 1 case in Illinois, the company having agreed to abide by the decision with regard to 13 other women who claimed similar disability.

It is important that in many of the reported cases symptoms developed several years after exposure had begun, and that intervals of 7 years or more elapsed between the time the individual left the employment which was the source of exposure and the time symptoms developed. The late development of symptoms and their resemblance to those of other diseases not only give reason to believe that some cases of radium poisoning have escaped diagnosis but also indicate the need for caution in evaluating the effectiveness of protective measures instituted in recent years.

Treatment of radium poisoning has proved ineffectual in those cases which show appreciable amounts of radioactivity. Some suggestive increase in the rate of excretion of radium has been obtained in response to decalcification treatment, but the proportion of stored radium excreted in this way is not large. It is conceivable that such treatment may be of value in very early cases in which no clinical symptoms of radium poisoning have yet appeared. At the present time no one in whose body significant amounts of radium have been deposited is known to have been freed from such radioactive deposits or permanently protected from their harmful effects.[15]

NATURE OF THE INDUSTRIES

Self-Luminous-Dial Painting

Size and location of plants and departments.

Employment in the self-luminous-dial industry during the period of the first World War has been estimated at about 2,000 persons.[16]

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[11] Occurrence of Malignancy in Radioactive Persons.

[12] Arkansas, Delaware, Idaho, Maryland, Michigan, New York, North Carolina, Ohio, Pennsylvania, Rhode Island, and Utah. These 12 States include practically all those which, in providing compensation for occupational diseases, name specifically the occupational diseases covered.

[13] The Occurrence and Prevention of Occupational Diseases Among Women, 1935–1938, pp. 24 and 25. Women's Bureau Bulletin 184. U. S. Department of Labor, Washington, 1941.

[14] Exposure terminated in 1925 in 2 cases, in 1926 in 1, and in 1929 in 1. Information was not available as to the time of exposure of the other 2.

[15] Radium Poisoning, by Harrison S. Martland, in A Textbook of Medicine by American Authors, edited by Russell L. Cecil, 5th ed., pp. 589–594. W. B. Saunders Co., Philadelphia, 1941.

[16] Industrial Bulletin, Vol. 20, No. 3 (March 1941), p. 95. New York State Department of Labor, Albany.

After the war, employment declined, and in March 1941 only 300 were employed in it. An expansion has again taken place, and it is estimated that approximately 1,000 persons are now working in dial-painting plants. There are at least 15 dial-painting plants or dial-painting departments of clock, instrument, or other manufacturing plants located in Connecticut, Illinois, Maryland, Massachusetts, New Jersey, New York, and Pennsylvania. Although the established dial-painting plants have developed their present methods and procedures after many years of experience, the actual equipment required is not elaborate, and there are no legal restrictions on the sale of radium or self-luminous compound. It is, therefore, quite possible that other dial-painting establishments exist and that more will arise in the future.

Processes.

Self-luminous compound is prepared in laboratories physically separated from the plants in which the compound is used. In the manufacturing laboratories, the phosphorescent material which constitutes more than 99 percent of self-luminous compound is prepared according to individual formulas which are generally regarded as trade secrets. Its most important constituent is phosphorescent crystalline zinc sulphide. Formerly radium or mesothorium, or both, was added to the zinc sulphide in order to produce self-luminescence, but at the present time only radium is used. The quantity of radium depends somewhat upon the quality of the self-luminous compound desired, but its concentration varies from 1 part in 4,000 to 1 part in 100,000 or 200,000.[17] The fluorescent zinc sulphide is prepared as a dry crystalline compound before the addition of the radioactive element. A sealed tube containing radium salt is opened under water in a ventilated hood, and the resulting solution is stored in a receptacle which is ventilated to remove radium emanation and lead-covered to reduce the exposure to radiation of persons in the room. A measured volume of the solution of radium salt is added, under a hood, to the zinc sulphide, which has been moistened just prior to the addition of radium. The resulting mixture is dried and screened. The compound is placed in glass containers of appropriate size, usually in lots of 50 to 100 grams, for transportation to the dial-painting plant or department in which it is to be used.

The application of self-luminous compound is carried on in dial-painting plants or in dial-painting departments of watch, clock, and instrument factories. The self-luminous compound as it is received from the manufacturer is generally stored in a lead-lined safe. As small working lots are required, they are weighed out, often in a separate weighing room, and placed in vials or crucibles. Each individual operator is supplied with a weighed quantity of self-luminous compound in a vial or crucible, sufficient for application to a known number of dials. The compound is usually supplied to the operators in its dry state, but occasionally it may be moistened with the required components of the paint before it is issued.

Operators work at individual benches, which in some plants are provided with ventilating hoods, or, rarely, at a long bench where they are provided with brushes, styluses, adhesives, and thinners, and with the cloths or tissues for pointing the brush and for other purposes. Trays of dials, hands, buttons, or other objects to which self-luminous compound is to be applied are placed at each worker's bench and provide the work materials for several hours. The compound, if issued in a dry state, is mixed by the operator to an appropriate consistency with a water paste or a lacquer-like adhesive and is applied to the parts of the object to be treated. Application of wet compound by means of a brush or stylus is the prevailing method. The completed tray of dials is removed to a darkroom for inspection before packing and shipment. Inspection and supervision may be carried out by the same person.

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[17] The Chemical Effects of Alpha Particles and Electrons, by Samuel C. Lind, p. 65. 2d ed., rev. Chemical Catalog Co., Inc., New York, 1928.

A dusting process, which is used much less frequently than painting, depends upon the application by transfer of an adhesive substance to the dial or other object to be treated, followed by the sifting on of self-luminous compound in dry powder form which adheres only to the coated part of the object and is brushed from the remaining surfaces.

Several other operations not involving the direct handling or use of radioactive substances are also carried on in plants where self-luminous paint is used. They include unpacking and laying out material for the operators, sewing hands on cards to facilitate painting of several at a time, degreasing metal parts prior to the application of self-luminous paint, spray-coating with lacquer or enamel to prepare or finish a dial, and white-enameling the figures of engraved dials prior to the application of self-luminous compound.

Recovery of radioactive material from previously treated objects, such as dials, is not generally practiced and is usually regarded as a procedure suitable only for the laboratory and not for the application plant. However, a certain amount of work is done in some plants in applying new self-luminous compound to objects which have previously been treated but which, over the course of years, have deteriorated beyond the point of usefulness. When such a procedure is carried on, the deteriorated compound, which still, of course, contains active radium, may be removed from the dial either under liquid or by applying a solvent or may be scraped or chipped off in the dry state.

Incandescent-Mantle Manufacture

The other industry with which this report is concerned as a source of exposure to radioactive substances is the manufacture of incandescent mantles, which are mantles for gas, gasoline, or kerosene lamps providing a brilliant white light because of the property of incandescence on heating.

From the time of the introduction of gas illumination, efforts were made along several lines to increase the luminosity of the flame. Attention was focused upon the rare earth minerals that could be brought to incandescence on heating. None of the mixtures was satisfactory, however, until the development in 1891 of the so-called "Auer mixture," which, after ignition, yields a final proportion of oxides of about 99 percent thorium and 1 percent cerium. This mixture is still in use and no other known mixture gives such satisfactory illumination. Thorium, like most of the rare earth minerals, is radioactive, giving rise by natural disintegration to mesothorium, radiothorium, thoron, and other members of its radioactive series.

Size and location of plants and departments.

Although the demand for incandescent-gas mantles has declined considerably since gas illumination has largely been replaced by electric illumination, gas mantles are still required for street lamps in some localities, for use with gasoline or kerosene lanterns, and to some extent for home illumination in the natural-gas regions. There are in the United States at least 5 plants that manufacture incandescent mantles—or departments in plants manufacturing these mantles as well as other products—located in Illinois, Indiana, Kansas, Pennsylvania, and Connecticut.

Processes.

Mantles are made from rayon-mesh fabric knit in the form of a tube. Operatives dip large rolls of this fabric tubing into the so-called "lighting fluid," a 25–50 percent solution of approximately 99 parts thorium and 1 part cerium nitrate. Small quantities of other nitrates, such as beryllium and magnesium, are added to strengthen the ash skeleton, and the fabric is treated with ammonia to convert the nitrates to hydroxides. After drying, the rolls are taken to operators of cutting and sewing machines, who cut them to suitable lengths and sew one end closed, thus producing individual bag-shaped units. After having been stamped with the manufacturer's marks, the open end may be threaded with an asbestos thread and the mantles shipped in this soft state suitable for attachment to lanterns. An alternative process involves the attachment of the mantle to metallic or other rigid supports, and its ignition in an intense flame. Ignition, or "burning-off," converts the hydroxides to oxides and hardens the mantle so that it assumes the familiar appearance of the incandescent mantle. Before shipment the mantles are dipped in collodion to strengthen them for transport. In the process of manufacture, especially in "burning-off," a number of mantles are broken. This is significant because the mantle scrap which thus accumulates is processed for reclamation of the thorium.

THE HAZARD OF INDUSTRIAL EXPOSURE TO RADIOACTIVE SUBSTANCES

The harmful effect of radioactive substances, discussed in the first section of this report, may arise when such substances enter the body either by ingestion or by inhalation, or from excessive exposure to external radiation.

Self-Luminous-Dial Painting

Sources of hazard.

The *ingestion* of radium paint by dial painters has been considered the chief cause of radium poisoning in the past. The regular practice in the plants where poisonings occurred was for the girls to point their brushes with their mouths, inevitably swallowing some radium-containing compound with each brush pointing. Most of the radioactive substance ingested in this way passes through the intestinal tract, but small amounts circulate in the blood and are deposited in the liver, spleen, and bones, ultimately accumulating in the skeleton.

The *inhalation* of solid radioactive substances gives rise to absorption and eventual storage in the skeletal system. The lungs also show considerable radioactivity. The deaths from severe anemia of several chemists engaged in the manufacture of self-luminous paint are considered to have been caused, in part at least, by inhalation of radioactive dust.[18] Radioactive dust may arise from the handling of self-luminous compound before it is moistened with adhesive, and from repair or refinishing work when deteriorated or improperly applied self-luminous compound is removed from dials in the dry state. Radioactive gaseous emanation is also present in the air wherever self-luminous compound is exposed, especially where large quantities are handled without adequate local ventilation.

The exposure of the whole body to gamma radiation, which is capable of producing skin lesions and anemia, has not been considered one of the chief hazards of painting self-luminous dials. In the past, however, some chemists engaged in the manufacture of self-luminous compound have been found to have skin lesions from this source of radiation. The National Bureau of Standards calls attention to the existence of this danger in close association with the other hazards from radiation occurring in the use of self-luminous compound.[19]

In attempting to appraise the hazard from radioactive substances under present conditions of manufacture and use of self-luminous compound the permissible limits and safe practices which have been proposed provide a frame of reference in which current practices may be examined. The English investigators Read and Mottram have proposed a maximum limit for radon of 1 x 10^{-9} curies per liter.[20] In this country, however, the National Bureau of Standards has proposed a more rigid limit for radon and has also recommended limits for deposited radium and whole-body gamma radiation:

Maximum permissible limits recommended by the National Bureau of Standards [21]

Deposit of radium in body of worker	0.1 micrograms of radium
Radon concentration in atmosphere	1 x 10^{-11} curies per liter [22]
Whole-body gamma-radiation exposure	0.1 roentgen per working day

The National Bureau of Standards adds this qualification: "In connection with the three types of hazards enumerated above, it is important to bear in mind that the tolerances have been determined under conditions where only one hazard was present. In the dial-painting industry all three hazards exist together, and this may reduce the tolerance on each. Insufficient information is available at present to determine to what extent this may occur. *It is therefore important to keep well below the tolerances stated, to insure safety.*" [23]

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[18] Occurrence of Malignancy in Radioactive Persons, by Martland.

[19] Safe Handling of Radioactive Luminous Compound, p. 2. National Bureau of Standards Handbook H27. U. S. Department of Commerce, Washington. May 1941.

[20] The "Tolerance Concentration" of Radon in the Atmosphere, by John Read and J. C. Mottram. British Journal of Radiology, Vol. 12, No. 133 (January 1939), p. 60.

[21] National Bureau of Standards Handbook H27, p. 3.

[22] 1 curie is the amount of emanation in radioactive equilibrium in a closed container with 1 gram of radium element. Hence 10^{-11} curies is a quantity of emanation which would be in equilibrium with 10 micromicrograms of radium element in a closed container.

[23] Handbook H27, p. 3.

Limitation of the supplies of self-luminous compound exposed in the workroom at one time, methods of ventilation, and close attention to good housekeeping are some of the ways of maintaining conditions of safety within the suggested limits, according to published descriptions of good practice. Some plants as a check on the effectiveness of these procedures obtain regular measurements of the radioactivity in the workrooms. Good practice also means careful supervision of the operators, darkroom inspection of operators before they leave for lunch and at the end of the day, and careful selection of operators with respect to personal qualifications. Preemployment and periodic physical examinations are required in several plants, but not all examinations include tests of radioactivity of the worker. Carefully performed tests of radioactivity provide evidence as to the advisability of permitting the exposure of any individual to continue. In accordance with safe practice only workers who are naturally neat and clean, careful and tidy, should be permitted to engage in such work.

Hazard under present conditions.

Measurements of the radioactivity in the atmosphere of dial-painting plants indicate that the proposed safe limits may be exceeded in some places. Evans and Goodman state that the radon content in radium-dial-painting plants that are modern and well ventilated has been found to range from 0.4×10^{-11} to 2.5×10^{-11} curies per liter of air. They add: "Our radon analyses of the air in a number of modern dial plants show that the radon concentration *can be* successfully maintained below 1×10^{-11} curies per liter, with consequent elimination of the pulmonary hazard."[24] [Italics ours.] However, in Evans' judgment, some dial plants fail to maintain a satisfactorily low air concentration of radon.[25]

Measurements of the radioactivity of dial painters show that a hazard continues to exist despite improvements in plant practices. Although the practice of pointing brushes with the mouth is generally accepted as the cause of the many cases of radium poisoning previously referred to, there is no doubt that dial painters can become radioactive even though they have never practiced mouth-pointing. A study conducted by the United States Public Health Service showed significant radioactivity, increasing with years of exposure, of some dial painters who had entered upon the occupation only after mouth-pointing had been discontinued. One of the conclusions was that "This continuing rate of accumulation [of radium] in Group A [no mouth-pointing] indicates that the abolition of pointing the brush with the mouth has not entirely solved the problem of radium deposition in the body."[26] Although there has been further improvement in safe practices since 1933, those who are now carrying on tests of radioactivity in dial painters state that some contemporary dial painters show evidence of radioactivity. In no painters who have worked exclusively under modern conditions has radioactivity of an order comparable to that in the advanced cases been found. The occurrence of any significant degree of radioactivity in dial painters, however, shows that absorption of radioactive compound can occur under present conditions.

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[24] Determination of the Thoron Content of Air and Its Bearing on Lung Cancer Hazards in Industry, by Robley D. Evans and Clark Goodman. Journal of Industrial Hygiene and Toxicology, Vol. 22, No. 3 (March 1940), pp. 89–99.

[25] Personal correspondence: Dr. William Schmidt of the Children's Bureau to Dr. Robley D. Evans, dated Nov. 19, 1941, and reply dated Dec. 5, 1941.

[26] Health Aspects of Radium Dial Painting: I. Scope and Findings, by Louis Schwartz, Fred L. Knowles, Rollo H. Britten, and Lewis R. Thompson. Journal of Industrial Hygiene and Toxicology, Vol. 15, No. 5 (September 1933), p. 365.

The emphasis placed upon the care necessary in selecting and supervising personnel by employers and technical experts indicates that some degree of hazard may be expected to continue to inhere in the use of self-luminous compound even under modern practices. Protective measures for preventing ingestion or inhalation of self-luminous compound require the intelligent cooperation of the operators. Observance of the principles of cleanliness, neatness in handling the materials of work, precaution as to eating and drinking in the workroom, as well as of other aspects of safe practice, implies intelligent, thoughtful, and prudent attention on the part of the workers. The handbook previously referred to states: "From the point of view of reducing hazards, it is also important that only workers who are naturally neat and careful should be employed. Continued carelessness or untidiness in handling material during the preliminary training period shall be reason for dismissal. * * * *Before an individual is employed he shall be informed in detail of all known dangers involved. He shall be instructed regarding rules and regulations which have been set up for his protection and he shall be directed to observe them in all details. It is suggested that those engaged in handling radioactive luminous compound familiarize themselves with the recommendations of this handbook.*" [27] Younger workers, as a group, cannot be expected to understand and observe such instructions as well as older workers. Moreover, when safe practices are not in general scrupulously attended to in the plant, it is not likely that the instruction of new workers as to known hazards is conscientiously carried out.

The existence, currently or recently, of practices now generally recognized as hazardous is evidence that the industry is not at present fully and effectively modernized. Examples of unsafe practices are:

(a) Home work, which presents grave dangers in the absence of supervision and protective measures, has been discovered to have been practiced within the past year (1941) by 24 individuals in 19 homes.

(b) A dusting process, considered to be much more hazardous than painting, the usual method, was in operation in one plant until recently.

(c) Repair and repainting of luminous articles was observed in one plant. The worn-out compound, which contains all the original radium with virtually unimpaired activity, was scraped from the dials in its dry state over a local exhaust assembly of doubtful efficacy, which was not in operation at the time of the visit, and, contrary to the recommendations of the Bureau of Standards, the operator wore no protective mask.

(d) Other practices were found that failed to meet the recommended standards of safety. These included the sharpening up of poorly painted numbers with a razor blade, giving rise to dissemination of radioactive particles in their dry state, and the weighing and bottling of luminous compound without the protection of a supplied-air type of "respirator" approved by the United States Bureau of Mines for such exposure, and, in some instances, without a respirator of any type.

There is, therefore, reasonable evidence that the luminous-dial industry is still hazardous, although less so than formerly. The degree of hazard is greater for young persons because of their immature judgment and sense of caution. The hazard exists in the workrooms where self-luminous compound is manufactured and in the workrooms of dial-painting plants or departments where self-luminous compound is stored or used.

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[27] Handbook H27, p. 5.

Incandescent-Mantle Manufacture

Sources of hazard.

Thoron, the gaseous emanation of mesothorium, constantly escapes into the air during the processes of mantle manufacture.

That this emission may lead to a high concentration of thoron in the air of the workroom is evidenced by observations in an incandescent-mantle factory in 1939 that revealed the following concentrations of thoron:

Concentrations of thoron in a contemporary incandescent-mantle factory[28]

	Curies of thoron per liter of air
Drying room	50×10^{-11}
Mantle soaking	400×10^{-11}
Cutting and drying	23×10^{-11}
Steaming	120×10^{-11}
Thorium reclamation	41×10^{-11}
Drying room	75×10^{-11}

These concentrations of thoron in a large plant believed to be representative of the industry may be compared with the maximum permissible limit for radon of 1×10^{-11} curies per liter proposed by the National Bureau of Standards. The concentrations reported in the accompanying table are from 23 to 400 times as great as the limit proposed by the Bureau of Standards handbook, and the greatest of them exceeds the more liberal proposed limit of 1×10^{-9} (100×10^{-11}) by 4 times.[29] Moreover, these concentrations of thoron are of the order of magnitude of those reported in the radioactive European mines.[30] Although some authorities believe that arsenic and chromate dust were contributing factors in the appearance of cancer in the European mines, many believe that the radioactive emanation was probably an important causal factor.

Hazard under present conditions.

In spite of the absence of conclusive proof, the leading authorities in the field of radioactive substances are of the opinion that continued exposure of workers to atmospheres containing concentrations of radon or thoron of 10^{-9} (100×10^{-11}) curies per liter is at least potentially hazardous and that there is a reasonable possibility that exposure to such concentrations may lead to the development of pulmonary cancer and may also contribute to the development of anemia.

It must be recalled, in this connection, that many years usually elapse between the exposure to radioactive substances and the development of symptoms of poisoning, and that the worker may have left the employment in which the exposure occurred a considerable time before the appearance of illness. Moreover, since the symptoms and characteristics of lung cancer arising from this source do not differ from those of nonoccupational primary lung cancer, the occupational origin would no doubt not be suspected in many cases.

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[28] Adapted from Determination of the Thoron Content of Air and Its Bearing on Lung Cancer Hazards in Industry, by Evans and Goodman, table 2, p. 95.

[29] Read and Mottram, *op. cit.*, p. 60.

[30] Occupational Cancer of the Lung, by Teleky.

The degree of hazard varies in the several processes of incandescent-mantle manufacture, but in all processes the concentration of thoron was found to be well above the proposed safe limit. Moreover, since there may be little or no segregation of processes within the factory, it is apparent that the hazard of continued inhalation of radioactive gas extends to all workers whose occupations are carried on in workrooms where incandescent mantles are manufactured.

EMPLOYMENT OF MINORS

In the earlier days of the self-luminous dial-painting industry many young girls were employed as dial painters. None of the plants visited employed any dial painters whose stated age was less than 18 years, except for one girl who was 17. However, girls between 18 and 20 are considered by employers to be at a desirable age for training, and many new employees in this age group are engaged. The age distribution of employees in 4 self-luminous dial-painting plants is shown in the following list.[31] Twenty-nine percent of the employees were 17 to 19 years of age, and 48 percent were under 21.

Stated age	*Number of operators*
Total	397
17	1
18	37
19	79
20	73
21 or over	207

The employment of many young workers under 21 also characterized the incandescent-mantle industry. Of the workers whose stated ages are given in the following list,[32] 34 percent were 17 to 19 years of age and 41 percent were under 21 years.

Stated age	*Number of operators*
Total	110
17	3
18	13
19	21
20	8
21 or over	65

During the summer, vacation employment is offered to other individuals under 18 years of age.

Industry Policies

As is indicated in the foregoing list, it is not the policy of dial-painting plants at present to hire workers younger than 18 years. With the exception of one plant, however, the age stated by the applicant was accepted and age certificates issued under State child-labor laws were not required. In one plant a birth certificate was filed for each employee.

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[31] Based on information obtained from factory superintendents or managers for September, October, or November 1941. In 3 of the 4 plants, employing 159 workers, the age is that stated by the employee; in 1 plant, employing 238 workers, the age given is that shown on the birth certificate.

[32] Ages were ascertained from plant records that were based principally on the statements of the employees.

There does not appear to be a uniform policy in the industry manufacturing incandescent mantles against the hiring of persons under 18 years of age.

Minimum-Age Regulations and Laws

No State law has expressly set a minimum age for work in connection with radioactive substances higher than that applicable to general factory work, usually 14 or 16 years. Nor have any State agencies expressly designated such occupations as hazardous, and therefore prohibited for minors.[33]

ATTITUDES TOWARD APPLICATION OF AN 18-YEAR MINIMUM-AGE STANDARD

The industrial hygienists, physicists, and other persons consulted who have had wide experience in connection with the hazards of radioactive substances have expressed general approval of the establishment of 18 years as the minimum age for employment in occupations characterized by exposure to radioactive substances. It is recognized that there is no legal control at present of the sale or use of radioactive compound, that a rapid expansion is now occurring in the industry, and that the effect of a hazardous-occupations order would be to prevent any possible influx of younger workers into the industry insofar as the child-labor provisions of the Fair Labor Standards Act cover such employment.

Employers in the self-luminous dial-painting industry have generally expressed themselves as in accord with the establishment of an 18-year minimum age for employment in most of the occupations in the industry, although they believe that there is little or no hazard associated with such work in modern, well-supervised dial-painting plants or departments. One plant manager stated that he regarded girls of 16 and 17 years as "kids" who do not belong in a dial-painting shop. In another plant the opinion was expressed that girls of 16 and 17 are less "reliable" than older workers. These opinions are in accord with the view that minors under 18 years of age are less likely than more mature workers to observe fully and faithfully the rules and regulations set up for their protection.

The technical experts consulted were of the opinion that all occupations in workrooms in which radium is stored or used in the manufacture of self-luminous compound are particularly hazardous for young persons; and that all operations carried on in workrooms where self-luminous compound is used are hazardous, including the occupations of weigher, operator, retoucher, workers on the repair and refinishing of old dials, inspectors, and supervisors. There was general agreement among technical experts that employees who work solely in offices of luminous-dial-painting plants, or in occupations carried on in workrooms separate from those in which self-luminous compound is used or worked upon, are not exposed to an appreciable hazard.

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[33] Virginia prohibits children under 18 years from being employed in any capacity in preparing any composition in which dangerous or poisonous chemicals are used. This might be interpreted as applying to the employment of minors under 18 years in connection with radioactive substances.

The opinion of persons who have studied the industry that manufactures incandescent-gas mantles is that there is significant hazard associated with all occupations carried on in workrooms in which incandescent mantles are manufactured.

CONCLUSIONS

1. A hazard to health because of exposure to radioactive substances is associated with the manufacture and application of self-luminous compound and the manufacture of incandescent mantles.

2. Ingestion or inhalation of radioactive substances may result in profound anemia, radiation osteitis, malignant tumors of bones or lungs, and death. External radiation of the body may result in skin lesions and anemia.

3. In spite of great improvements in safe practices since the many deaths from radium poisoning in the earlier days of the self-luminous dial-painting industry, there continues to be some hazard in this industry at the present time.

4. Reported measurements of radioactivity in the air of a large plant that manufactures incandescent mantles and that is believed to be representative of the industry showed concentrations of radioactive gas which were from 23 to 400 times as great as the maximum permissible limit recommended by some authorities and as much as 4 times the most liberal proposed maximum permissible limit.

5. The hazard of exposure to radioactive substances is present in all occupations in workrooms in which radium is stored or used in the manufacture of self-luminous compound, and in which self-luminous compound is made, processed, or packaged; in all occupations in workrooms in which self-luminous compound is stored, used, or worked upon; and in all occupations in workrooms in which incandescent mantles are made from fabric and solutions containing thorium salts, or are processed or packaged.

6. The hazard is greater for young persons because they are not so likely as older persons to possess the qualities of carefulness, neatness, forethought, and attention to personal hygiene that are essential in the observance of safe practices.

7. The opinion was generally held by the employers interviewed that minors under 18 years of age should not be employed in self-luminous dial-painting plants or departments. While employers generally believed that there is little hazard associated with occupations in modern dial-painting plants or departments, the opinion expressed by several employers that minors of 16 and 17 years are less reliable than older workers is added reason to believe that persons under 18 are less likely to observe rules for safe practice conscientiously.

8. Industrial hygienists and other experts who have studied the hazard of exposure to radioactive substances are agreed that it would be desirable to adopt an 18-year minimum-age standard for employment in occupations hazardous because of exposure to radioactive substances.

Appendix A.—Legal Basis for the Investigation

The investigation here reported has been conducted by the Industrial Division of the Children's Bureau pursuant to the regulation Procedure Governing Determinations of Hazardous Occupations,[1] issued by the Chief of the Children's Bureau on November 3, 1938, and to the authority conferred by section 3 (l) of the Fair Labor Standards Act of 1938 (Act of June 25, 1938, ch. 676, 52 Stat. 1060, U. S. Code, title 29, sec. 201). This subsection, which defines oppressive child labor as that term is used in the act, provides in part as follows:

> (l) "Oppressive child labor" means a condition of employment under which (1) any employee under the age of sixteen years is employed by an employer * * * in any occupation, or (2) any employee between the ages of sixteen and eighteen years is employed by an employer in any occupation which the Chief of the Children's Bureau in the Department of Labor shall find and by order declare to be particularly hazardous for the employment of children between such ages or detrimental to their health or well-being; * * *.

The regulation Procedure Governing Determinations of Hazardous Occupations was issued for the purpose of establishing an orderly procedure for determining and declaring occupations to be particularly hazardous for the employment of minors 16 and 17 years of age or detrimental to their health or well-being. It provides in part as follows:

> Section 421.1. *Investigation and conference.*—Preparatory to the making of a finding by the Chief of the Children's Bureau that an occupation or a group of occupations is particularly hazardous for the employment of minors between 16 and 18 years of age or is detrimental to their health or well-being, a study shall be made of information obtained by the Bureau or submitted to it with respect to the hazardous or detrimental nature of such occupation or occupations. Conferences may be held with representative employers and workers in the industry, experts in industrial health and safety, and others for the purpose of discussing the nature and characteristics of the occupation or occupations under consideration. * * * A report of facts and conclusions with respect to the hazardous or detrimental nature of the occupation or occupations under consideration shall be prepared upon the basis of such information and evidence.

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[1] Procedure Governing Determinations of Hazardous Occupations, Title 29—Labor, Chapter IV—Children's Bureau, Child Labor—Part 421. Federal Register, Vol. 3 (Nov. 5, 1938), p. 2640.

Appendix B.—Hazardous-Occupations Order No. 6

April 2, 1942.

Occupations Particularly Hazardous for the Employment of Minors Between 16 and 18 Years of Age or Detrimental to Their Health or Well-Being

Section 422.6. Occupations involving exposure to radioactive substances. (a) *Finding and Declaration of Fact.*—By virtue of and pursuant to the authority conferred by section 3 (l) of the Fair Labor Standards Act of 1938 [1] and pursuant to the regulation prescribing the procedure governing determinations of hazardous occupations; [2] an investigation having been conducted with respect to the hazards for minors between 16 and 18 years of age in employment in occupations involving exposure to radioactive substances; and a report of the investigation having been submitted to the Chief of the Children's Bureau;

Now, therefore, I, Martha M. Eliot, M. D., Acting Chief of the Children's Bureau of the United States Department of Labor, hereby find and declare that the following occupations involving exposure to radiactive substances are particularly hazardous and detrimental to health for minors between 16 and 18 years of age:

> Any work in any workroom in which (*a*) radium is stored or used in the manufacture of self-luminous compound, (*b*) self-luminous compound is made, processed, or packaged, (*c*) self-luminous compound is stored, used, or worked upon, or (*d*) incandescent mantles are made from fabric and solutions containing thorium salts, or are processed or packaged.

(b) *Definitions.* As used in this section—

> (1) The term "self-luminous compound" shall mean any mixture of phosphorescent material and radium, mesothorium, or other radioactive element.
>
> (2) The term "workroom" shall include the entire area bounded by walls of solid material and extending from floor to ceiling.

This order shall not justify noncompliance with any Federal or State law or municipal ordinance establishing a higher standard than the standard established herein. This order shall become effective on May 1, 1942, and shall be in force and effect until amended or repealed by order hereafter made and published by the Chief of the Children's Bureau.

Martha M. Eliot, M. D.,
Acting Chief of the Children's Bureau.

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[1] Act of June 25, 1938, ch. 676, 52 Stat. 1060, U. S. Code, ti. 29, sec. 201.

[2] Issued November 3, 1938, pursuant to authority conferred by section 3 (l) of the Fair Labor Standards Act of 1938; published in the Federal Register, Vol. 3 (Nov. 5, 1938), p. 2640, Procedure Governing Determinations of Hazardous Occupations.